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$$\dot{\eta}_{x,acc,j} = \dot{\eta}_{x,in,j} - \dot{\eta}_{x,out,j} + \dot{\eta}_{x,gen,j} \qquad j = 1, 2 \ldots M$$

$$\boxed{\dot{\eta}_{x,acc,j} = \dot{\eta}_{x,gen,j}} \longrightarrow \frac{d}{dt}\int_\beta x_i \, d\beta = \int_\beta (\ldots)\, d\beta$$

* well mixed assumption

$$\frac{d}{dt} x_j \beta = (\ldots)\beta$$

$$x_j \frac{d\beta}{dt} + \beta \frac{dx_j}{dt} = (\ldots)\beta$$

$$\dot{x}_j = (\ldots) - x_j \beta^{-1} \dot{\beta} \qquad \beta = x V_R$$

$\beta^{-1}\dot{\beta} = \mu$ = dilution due to growth

$\beta = x V_R$ $\quad V_R$ = reactor volume

$$\dot{\beta} = x \dot{V}_R + V_R \dot{x}$$

$$\beta^{-1}\dot{\beta} = \frac{\dot{x} V_R}{x V_R} + \frac{\dot{V}_R x}{x V_R} = \frac{\dot{x}}{x} + \frac{\dot{V}_R}{V_R}$$

$\dot{x} = \mu x$ $\quad \dot{V}_R = 0$

$$\boxed{\beta^{-1}\dot{\beta} = \frac{\dot{x}}{x} = \mu}$$

~~* deterministic MM (where (Varner))~~

since cell free $\dot{x} = 0$

so $\mu = 0$ therefore no dilution